Journal of Forestry Research (2009) 20(1):15–22
DOI 10.1007/s11676-009-0003-5

RESEARCH PAPER

Aboveground nutrient components of *Eucalyptus camaldulensis* and *E. grandis* in semiarid Brazil under the nature and the mycorrhizal inoculation conditions

Marcela C. Pagano[1]*, Antonio F. Bellote[2], Maria R. Scotti[1]

[1]*Microorganism-Plant Interaction Laboratory, Institute of Biological Sciences, Federal University of Minas Gerais, Av. Antônio Carlos, 6627, Pampulha, CEP: 31270-901, Belo Horizonte, MG, Brazil.*

[2]*Embrapa Forestry, Estrada da Ribeira, km 111, Caixa Postal 319 - Colombo, PR - 83411-000- , Brazil.*

Abstract: A study was conducted to evaluate the aboveground biomass, nutrient content and the percentages of mycorrhizal colonization in *Eucalyptus camaldulensis* and *Eucalyptus grandis* plantations in the semiarid region (15° 09' S 43° 49' W) in the north of the State of Minas Gerais in Brazil. Results show that the total above-ground biomass (dry matter) was 33.6 Mg·ha^{-1} for *E. camaldulensis* and 53.1 Mg·ha^{-1} for *E. grandis*. The biomass of the stem wood, leaves, branches, and stem bark for *E. camaldulensis* accounted for 64.4%, 19.6%, 15.4%, and 0.6% of the total biomass, respectively (Table 2); meanwhile a similar partition of the total above-ground biomass was also found for *E. grandis*. The dry matter of leaves and branches of *E. camaldulensis* accounted for 35% of total biomass, and the contents of N, P, K, Ca, Mg, and S in leaves and branches accounted for 15.5%, 0.7%, 12.3%, 22.6%, 1.9%, and 1.4% of those in total above-ground biomass, respectively. In the trunk (bark and wood), nutrient accumulation in general was lower. Nutrient content of *E. grandis* presented little variation compared with that of *E. camaldulensis*. Wood localized in superior parts of trunk presented a higher concentration of P and bark contained significant amounts of nutrients, especially in *E. grandis*. This indicated that leaving vegetal waste is of importance on the site in reducing the loss of tree productivity in this semi-arid region. The two species showed mycotrophy.

Keywords: Eucalyptus; biomass; nutrient components; semi-arid region; mycorrhizal symbioses; Brazil

Introduction

Eucalyptus, native from Australia, with more than 600 species, has been used as a monoculture in afforestation programs. In many countries these plantations are used in cellulose industries, pharmaceutics and hygiene. The *Eucalyptus* species present characteristics suitable for commercial use, such as fast growth, high cellulose production and resistance to environmental stress and diseases (Santos et al. 2001). In Brazil, for a sustainable production in intensive systems of wood extraction, to keep or improve the nutritional soil levels is essential. Studies showed a general upward trend in N fertilizer requirements in commercial eucalypt plantations (Gonçalves et al. 2004; Laclau et al. 2005; Corbeels et al. 2005) and the N inputs are a major cost in Brazilian silviculture not to mention the potential risks of pollution and leaching of nitrates in tropical forest soils (Fisher and Binkley 2000).

Gonçalves (1995) reported the nutrient accumulation in 5–6 year-old *Eucalyptus grandis* plantations in Brazil and observed that during harvesting part of nutrients remain in the ecosystem accumulated in leaves, branches and litter when these are not removed from the site. Nevertheless, 30% of nitrogen (N), phosphorus (P) and calcium (Ca), and 43% of potassium (K) are removed when wood is extracted. The loss of N, P, K and Ca increases 40%, 60%, 65%, and 48%, respectively, when bark is extracted with wood. Mineral fertilization is a common practice to improve productivity; however, management policies need further studies. Most biomass and nutrients accumulated by planted *E. grandis* occurred between two and five years of age, when the leaf area is expanding. *E. camaldulensis* is very widely distributed in inland Australia along river banks. This fast growing tree species can tolerate moderate salinity, alkalinity, extended dry seasons and waterlogging, and is extensively planted throughout the world for purposes such as shade, shelter, agroforestry, furniture and industrial wood production (Midgley et al. 1989; Marques Júnior et al. 1996). The rotation length is about 3–5 years for *E. camaldulensis* and 7 years for *E. grandis* (Campinhos

Foundation project: This study was financed by CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior)

Received: 2008-03-28; Accepted: 2008-10-30

The online version is available at http://www.springerlink.com

Biography: Marcela Claudia Pagano (1966-), *Corresponding author, female, Major: Botany; Postdoctoral researcher at Federal University of Minas Gerais, Brazil . e-mail: marpagano@gmail.com

Responsible editor: Chai Ruihai

1999).

Sandy soils are characterized by little water and nutrient retention, which means difficult management and vegetation development in these areas, the presence of arbuscular mycorrhiza being important to increase the capacity of water and nutrient absorption by plants (Córdoba et al. 2001). It is important then to know the mycorrhizal condition of species in order to allow for research on seedlings production and technologies for a successful reforestation.

Arbuscular mycorrhiza (AM) are substantially involved in the vegetative state of the mycotrophic plants, defining their ecologic niches, influencing vegetal communities composition, maintenance and soil fertility, plant fitness, and nutrient turnover (Jeffries et al. 2003). Some plant species, like *Eucalyptus* spp., have the capacity to form two types of mycorrhizas, arbuscular and ectomycorrhiza (ECM) (Malajczuk et al. 1981; Zambolim and Barros 1982). Establishment of AM association in *Eucalyptus* has been known for over 20 years, and the benefits of symbiosis have proved commercially relevant (Zambolim and Barros 1982; Coelho 1997; Gomes and Trufem 1998; Grazziotti et al. 1998; Santos *et al*. 2001). Studies of AM inoculation on eucalypt are increasing (Standish et al. 2007) and *Glomus* sp. was used as inoculum (Arriagada et al. 2007). As regards ECM, Molina et al. (1992) and Thomson et al. (1996)'s studies suggest that the majority of fungi, selected for their enhancement of seedling growth, may persist only for short periods in the field, where they are replaced by wild populations. Whereas, Pampolina et al. (2002) showed the significance of ECM in immobilizing P and other nutrients as well as the impact of P fertilization, as well as, Chen et al. (2000) and Mason et al. (2000) recommended the inoculation with tested ECM. There are numerous studies on ECM; however, works on *E. camaldulensis* and *E. grandis* AM/ ECM colonization in field conditions are to the best of our knowledge few.

The need to evaluate the success of these *Eucalyptus* spp. at the Jaíba region motivated this study of plant nutrient content and mycorrhizal status, aiming at increasing the possible ways of forest management in the region, and as a productive model for revegetation of local degraded areas with the objective of mixed them with native local species. This information is essential to identify methods for sustainable management.

The objective of the present study was: (1) to evaluate growth and quantify nutrient content of aboveground dry mass in 28-month-old pure stands of *Eucalyptus camaldulensis* and *E. grandis*, and (2) to examine the mycorrhizal root colonization.

Materials and methods

Study area, design, determination of biomass and nutrient quantification

The study area is located in the semiarid region (15°09' S 43°49' W) in the north of the State of Minas Gerais in Brazil, and is characterized by annual pluviometric rates of 800 mm concentrated in the spring-summer months from November to January, there being about 10 dry months (Prado 2003). According to Köppen, the climate of the region is BSh type (semiarid) (Carvalho 2003). Mean annual air temperature ranges from 24.2–28.1ºC, with mean annual temperatures of 34ºC in the hottest month (January) and 14.8ºC in the coldest month (July). Annual precipitation is 749 mm. Precipitation in December and July are 217 mm and 1 mm, respectively (Mocambinho Agroclimatic Station). Predominant soil types are Quartzarenic Neosoil with high infiltration rate. Furthermore, they are moderately acid and have small amounts of soil organic matter.

The present study focuses on *Eucalyptus* monocultures within the scope of a broad project dealing with the introduction of mixed and monocultures of *Eucalyptus* in a 10-ha experimental area, after the woody Caatinga had been cut and occupied by degraded vegetation named "Carrasco", with the aim of providing wood supply and minimising exploratory actions in biological reserves in the northwest of Minas Gerais state, Brazil. The experimental site (1.5 ha) was cleared of "Carrasco" vegetation (with retards the natural succession of forest) and *Eucalyptus camaldulensis* Dehnh and *E. grandis* Hill ex Maiden were cultivated in monocultures. Seedlings were transplanted during the rainy season in 2001, using a randomized block design with 42 plants, which were randomly distributed in each of the three blocks per site. Each block was composed by one plot of 378 m^2 (21m×18 m) with single plantations and 42 plants per block, with a spacing of 3m×3m. These plots were irrigated for about 10 months (Duarte et al 2006, Pagano et al. 2008).

For the present study we selected two experiments: 1- *E. camaldulensis* inoculated with AMF, and 2- *E. grandis* inoculated with AMF. The AMF inoculum consisted of a mix of three species *Gigaspora margarita, Scutellospora heterogama* and *Glomus brohultii* from the ICB-UFMG laboratory collection. Endomycorrhizal inoculation was accomplished by placing 1 ml of suspension composed of 50 spores of each AMF species.

Fertilization consisted in triple superphosphate (400 $kg \cdot ha^{-1}$), KCl (305.6 $Kg \cdot ha^{-1}$), $MgSO_4 7H_2O$ (40 $kg \cdot ha^{-1}$), $ZnSO_4 7H_2O$ (37.4 $kg \cdot ha^{-1}$), $Mo7O_2 4H_2O$ (1.4 $kg \cdot ha^{-1}$), urea (177.6 $kg \cdot ha^{-1}$) corresponding to 80% of complete fertilization following Somasegaran and Hoben (1985), and was applied at the beginning of the experiment. Plantation was then carried out and, when necessary, ant colonies were exterminated with formicide. In subsequent years, plantations were rid of ants, weeds and low branches.

Soil samples were collected from the top 20 cm of 3 spots/block/experiment (3 subsamples x 3 blocks x 2 experiments). Composite samples (2) were analyzed for chemical and physical properties. The soil analysis was performed by Embrapa - Brazilian Agricultural Research Corporation (1979). After carefully removing the surface organic materials and fine roots, the soil was sieved through a 2-mm mesh screen. Soil pH (H_2O), cation exchange capacity (CEC) determined by the ammonium acetate 1N method at pH 7.0, and percent BS (base saturation) were determined. O.M. (organic matter) was extracted according to Walkley and Black, as described by Nelson and Sommer (1982).

Mean diameter at breast height (1.3 m) over bark (D) (BHD, cm) and mean height of *E. camaldulensis* and *E. grandis* were calculated for each treatment. We selected three trees at random. They were chainsawed and sampled for subsequent nutrient analysis. Branches were separated from the trunk and all the leaves were

collected at field. Then, total fresh weight of leaves, branches, bark and trunk wood of the sampled trees were determined at EPAMIG Company, Mocambinho. Sampling was done in April, between summer and autumn, following Bellote (Personal communication).

Dry mass production and nutrient concentration of *Eucalypus* spp. cultivated in monoculture were evaluated at 28 months. The growth model was based on individual trees. Trunk samples consisted in 3.0 cm thick discs removed at each trunk, at base and 25%, 50%, 75% and 100% of height, including BHD, as proposed by Shimoyama (1990). For each disc, the bark was separated from the wood. This measurement served as a reference for wood density (wd) determination. These samples (weighed after immersion) were dried in a circulation oven at temperatures ranging from 65°C, until constant weight. Finally, samples were weighed with an analytical balance in order to obtain dry weight (dw) and the dry biomass of the components in each tree was calculated proportionally.

Total dry weight of leaves was obtained against composite samples of fresh weight, by using the following equation:

$$TDW = (TFW \times SDW) / SFW \quad (1)$$

where, *TDW* is the total dry weight (g), *TFW* the total fresh weight (g), *SDW* the sample dry weight (g), and *SFW* is the sample fresh weight (g).

Discs were used to calculate wood density of each subcompartment (bark and trunk wood), in each section of trunk, by the hydrostatic balance method, according to Bellote (1990).

$$bd = DW / (FW - IW) \quad (2)$$

where *bd* is the basic density (g/cm^3), *DW* the dry weight, *FW* the saturated fresh weight (g), and *IW* is the immersed weight (g). Bark was removed from stem sections used to determine wood density. Dry mass of the sample was determined after oven drying for 48 h at 105°C.

Samples were taken of BHD, D5 (disc 5) and D6 sections for determination of mineral nutrient levels at EMBRAPA-Maize and Sorghum Soil Analyses Laboratory. Samples were dried at 75°C, digested in nitric-perchloric mixture and analyzed for macronutrients. Phosphorus was analyzed by the ammonium phosphomolybdate method. Calcium, potassium and magnesium were analyzed by atomic absorption and potassium by flame photometry. After sulfuric digestion, Nitrogen (N) was determined by Kjeldahl method. These procedures are in according with Sarruge and Haag's methodology (1974). Nutrient concentrations of D2 sample were used to calculate wood (under bark) and bark nutrient concentrations (Young and Carpenter 1976).

Total tree volume (bark and trunk wood) was calculated by the Smalian equation which expressed the sum of segments of length calculated, which make up the trunk)

$$V = 1/2 \times (\pi D^2/4 + \pi d^2/4) \times h \quad (3)$$

where, *V* is the log volume (m^3), *D* the log major diameter (cm), *d* the log minor diameter (cm), and *h* is the log height (m).

Based on basic density and volume, total dry weight (W) was determined by using the following equations:

$$W = bd \times V \quad \text{(for bark and trunk wood)} \quad (4)$$

where, *W* is the weight (g), *bd* the basic density (g·cm^{-3}), and *V* the log volume (m^3).

To find out tree nutrient content, the model considered differences in concentration in stem compartment, that is, in bark and wood and also in leaves and branches. Bark volume was obtained through the difference between volumes with bark and without bark. The sum of leave and branches provided 12 samples, which yielded 12 determinations of nutrient levels. Discs (18 samples) provided 16 density determinations (2 samples were contaminated), besides allowing for calculating nutrient content in each tree log and each compartment analyzed.

Macronutrient stock (kg·ha^{-1}) in the aboveground biomass was calculated on the basis of the dry mass estimation (kg·ha^{-1}) and the macronutrient concentrations (g·kg^{-1}) obtained in the present study. The sum of the values for each component provided the total nutrient content (kg·ha^{-1}) of aboveground dry mass.

Root colonization

Roots of *Eucalyptus* spp. were collected by excavating from the trunk to the lateral root system of each tree. Four root samples were harvested around the tree, and mixed together. Samples were collected from three trees at each block and were fixed in FAA solution (formalin:alcohol:acetic acid) until samples could be processed. Roots were stained and assessed for mycorrhizal infection as follows. Roots were taken from the 1/2 FAA, washed several times in tap water and bleached in 10% (w/v) KOH (Phillips and Hayman 1970) overnight and then heated to approximately 90ºC in a water bath for 1 h. The cooled root samples were washed and stained with 0.05% trypan blue according to Phillips and Hayman (1970). Roots were cut into 1-cm segments and thirty 1-cm-root fragments were examined per sample for their arbuscular mycorrhizal (AM) status under a compound microscope (100 X). If at least one root segment was found to contain fungal mycelia, arbuscules or vesicles, then the sample was considered as an AM plant, recorded as ''+''. Plants were recorded as non-mycorrhizal (''-'') when neither arbuscules/vesicles nor fungal mycelia were detected in their root cortical cells. Quantification of mycorrhiza colonization was according to McGonigle et al. (1990), and results were expressed as percentage of colonized segments. Roots colonized by ectomycorrhizal fungi (presence of Hartig net) were included when calculating the percentage of root length colonized by ECM. Dual mycorrhizae (AM and ECM) were observed and individually recorded for calculation. These data were arcsin $(x/100)^{1/2}$ transformed. The data were subjected to one-way ANOVA using MINITAB software version 13.2 and means were compared by Tukey test ($P < 0.05$).

Results and discussion

The soil at the research site showed a pH ranging between 6.1 (*E. camaldulensis*) and 5.8 (*E. grandis*) in the topsoil (Table 1).

Textural composition presents 84% sand. Organic matter levels were found to be low in both *E. camaldulensis* and *E. grandis* monocultures, compared to those of foredunes (0.8%) in Brazil (Córdoba et al. 2001). The CEC was low and the percentage of BS (base saturation) was medium in *E. camaldulensis* and in *E. grandis* monoculture. In general, soil presented a high content of Zn, Cu and Fe (Table 1), which is in accordance with other reports that showed an improved acquisition of Zn and Cu by arbuscular mycorrhizal (Rillig 2004).

Table 1. Chemical analysis of the soil from the sampling site of *Eucalyptus camaldulensis* and *E. grandis* monocultures inoculated with arbuscular mycorrhizal fungi (AMF) soils at 2 years (Jaíba, Minas Gerais, Brazil)

Species	pH (H_2O) 1:1	Soil organic matter ($mg \cdot g^{-1}$)	Available. P ($mg \cdot L^{-1}$)	Available. K ($mg \cdot L^{-1}$)	Exchange Iron (cmol (+)·kg-^{1}) . Al^{3+}	. Ca^{2+}	. Mg^{2+}	CEC ($cmol(+) \cdot kg^{-1}$)	Base saturation (%)
E. camaldulensis	6.1	0.7	3.96	80	0	2.27	0.57	4.9	61
E. grandis	5.8	0.7	2.89	68	0.1	2.05	0.45	4.8	55
Species	Total porosity	Zn ($cmol(+) \cdot kg^{-1}$)	Cu ($cmol(+) \cdot kg^{-1}$)	Mn ($cmol(+) \cdot kg^{-1}$)	Fe ($cmol(+) \cdot kg^{-1}$)	Texture (%)[a] Coarse sand	Fine sand	Clay	Silt
E. camaldulensis	44.46	1	0.5	318	170	48	36	16	0
E. grandis	41.08	1.9	0.5	388	176	52	32	13	3

[a] Mean of two measures from one composite sample. Particle size distribution: coarse sand 2–0.2 mm, fine sand 0.2–0.02 mm, silt 0.02–0.002 mm and clay < 0.002 mm. mg L^{-1} = milligram per liter, CEC = cation exchange capacity.

The height (12.2 m) of *E. camaldulensis* observed in this study was higher than that (10.4 m) previously reported by Bernardo *et al*. (1998) in Cerrado soils in southeastern Brazil, at age 41 months, and the mean diameter was bigger than that in conventional fertilization plantation (Table 2). The above-ground biomass was 33.6 $Mg \cdot ha^{-1}$ for *E. camaldulensis* and 53.1 $Mg \cdot ha^{-1}$ for *E. grandis*. Of the total above-ground biomass of *E. camaldulensis,* the stem wood, leaves, branches, and stem bark account for 64.4%, 19.6%, 15.4%, and 0.6%, respectively (Table 2), and, a similar partition of the total above-ground biomass was also found for *E. grandis* (66.6%, 16.1%, 17.1%, and 0.2% spread in the stem wood, leaves, branches, and stem bark, respectively). The aboveground biomass (3.1 $Mg \cdot ha^{-1}$) of *E. grandis* in the present study was higher than that obtained by Faria et al. (2002) (46.4 $Mg \cdot ha^{-1}$) at 80 months-old stands of this species in a Cerrado region of Minas Gerais, whereas the stem volume (75.9 $m^3 \cdot ha^{-1}$) was lower than that observed in Cerrado (87.9 $m^3 \cdot ha^{-1}$). Almeida et al. (2007) predicted a lower stem volume (approximately 50 m^3 ha^{-1}) for *E. grandis* on Brazil´s Atlantic coast. Biomass distribution in descending order was: wood> leaves> branches> bark, for *E. camaldulensis* and, wood> branch> leaves> bark for *E. grandis* (Table 2).

Table 2. Characteristics of *Eucalyptus camaldulensis* and *E. grandis* monocultures inoculated with arbuscular mycorrhizal fungi (AMF), after 28 months of growth, at Jaíba, Minas Gerais, Brazil

Species	Height (m)	Diameter (cm)	Above-ground dry mass ($Mg \cdot ha^{-1}$)	Canopy dry mass ($Mg \cdot ha^{-1}$)	Leaves dry mass (g)	Branches dry mass (g)	Stem bark (g)	Wood (g)	Stem Volume ($m^3 \cdot ha^{-1}$)
E. camaldulensis	12.2 (0.4)	10.5 (0.3)	33.6 (6.5)*	11.7 (3.4)	5916.7 (1208)	4645.5 (2155)	179.7 (54.4)	19475.5 (2833)	42.8 (4.4)
E. grandis	12.9 (0.8)	11.8 (0.8)	53.1 (1.4)*	17.6 (5.1)	7703.1 (1814)	8180.2 (2800)	87.3 (24.3)	31834.1(3639)	75.9 (4.9)

Dates from monocultures with 3 m × 3 m spacing. Standard deviations of means between brackets. N=3. * significant values at 0.05 level

Table 3 shows the results of the content, average amount and ratio (percentage) of some selected micro- and macronutrients immobilized in each component of the aboveground biomass of *E. camaldulensis* and *E. grandis*. We observed that 33.2% of nutrients were accumulated in *E. camaldulensis* leaves, 6.2% in wood, 21.6% in branches, and 38.8% in stem bark.

For *E. camaldulensis,* the contents of N, P, K, Ca, Mg, and S in the total biomass were 122.7, 6.4, 99.8, 208.9, 16.1, and 11.2 $kg \cdot ha^{-1}$, respectively. The dry matter of leaves and branches accounted for 35% of the total biomass, and the contents of N, P, K, Ca, Mg, and S in leaves and branches accounted for 15.5%, 0.7%, 12.3%, 22.6%, 1.9%, and 1.4% of those in total above-ground biomass, respectively. In the trunk (bark and wood), which represents the remaining 65% of the total above-ground biomass, 4.5% of N, 0.28% of P, 7.4% of K, 31.3% of Ca, 1.1% of Mg, and 0.6% of S were accumulated. Thus the canopy (leaves and branches) concentrates 54.73% nutrients of total aboveground biomass. Leaves have most tree living cells that tend to accumulate larger quantities of nutrients, due to respiration and photosynthesis (Kramer and Koslowski 1979).

For *E. grandis,* the contents of N, P, K, Ca, Mg, and S in the total biomass were 224.4, 10.7, 103.1, 225.4, 26.5, and 12.6 $kg \cdot ha^{-1}$, and the contents of N, P, K, Ca, Mg, and S in leaves and branches accounted for 23.6%, 1.1% , 10.5%, 20.9%, 2.6%, and

1.1% of those in total aboveground biomass (Table 3). In the trunk (bark and wood), which represents the remaining 66.8% of the total aboveground biomass, 6.3% of N, 0.34% of P, 4.7% of K, 26.4% of Ca, 1.8% of Mg, and 0.6% of S were accumulated.

The contents of N observed in our study were similar to the results obtained by Hunter (2001), who reported an average N content of 16 mg/g for *E. grandis* at 37 months and 14 mg/g for *E. camaldulensis* in a mixed plantation with 2m×2 m spacing. This corroborates other studies of nutrient contents of forests (Poggiani et al. 1983; Boerner 1984; Pereira et al. 1984; Timmer and Morrow 1984, Hopmans et al. 1993). In general, the concentrations for N varied as foliage > branches, bole bark, roots > bole wood. Harrison et al. (2000) showed a higher N concentration in leaf and bark in *E. camaldulensis* in Cerrado soils, but the same concentrations in branches and wood. Schumacher and Poggiani (1993) reported higher N, P and K concentrations in leaves and highest concentrations of Ca and Mg in bark in *E. camaldulensis* and *E. grandis*. Dell et al. (1995) suggest that N leave concentrations for *Eucalyptus grandis* × *Eucalyptus urophylla* must be between 18 to 29 $g \cdot kg^{-1}$.

Table 3. Results of average content, average amount and ratio of nutrients in the different components of above-ground biomass of *Eucalyptus camaldulensis* and *E. grandis* inoculated with AMF, at Jaíba, Minas Gerais, Brazil

Species	cp	N			P			K		
		$g \cdot kg^{-1}$	$kg \cdot ha^{-1}$	%	$g \cdot kg^{-1}$	$kg \cdot ha^{-1}$	%	$g \cdot kg^{-1}$	$kg \cdot ha^{-1}$	%
E. camaldulensis	Leaves	13.1	86.2	10.7	0.5	3.6	0.4	8*	52.8	6.5
	Branches	5.8	30.4	4.8	0.4	2.3	0.3	7.1*	36.8	5.8
	Wood	2.4	2.6	1.9	0.1	0.1	0.08	2.3	2.5	1.8
	Bark	3.1	3.4	2.5	0.2	0.2	0.2	6.8	7.5	5.5
E. grandis	Leaves	17.9	153.3	16.9	0.7	6.2	0.6	5.9*	50.7	5.6
	Branches	6.9	63.6	6.6	0.4	4.1	0.4	5.1*	46.8	4.8
	Wood	2.2	2.4	2.0	0.1	0.1	0.1	1.6	1.7	1.5
	Bark	4.5	5	4.2	0.2	0.2	0.24	3.4	3.7	3.2
Species	cp	Ca			Mg			S		
		$g \cdot kg^{-1}$	$kg \cdot ha^{-1}$	%	$g \cdot kg^{-1}$	$kg \cdot ha^{-1}$	%	$g \cdot kg^{-1}$	$kg \cdot ha^{-1}$	%
E. camaldulensis	Leaves	16.2	106.4	13.2	1.7	11.2	1.4	1	6.7	0.8
	Branches	11.6	59.8	9.4	0.6	3.3	0.5	0.7	3.6	0.5
	Wood	2.2	2.4	1.8	0.3	0.3	0.2	0.3	0.3	0.2
	Bark	36.1	40.1	29.5	1.1	1.2	0.8	0.4	0.4	0.3
E. grandis	Leaves	12.3	105.8	11.7	1.9	17	1.8	0.7	8.3	0.7
	Branches	9.7	88.5	9.2	0.8	7.4	0.7	0.4	3.6	0.3
	Wood	1.3	1.4	1.2	0.2	0.2	0.2	0.3	0.3	0.2
	Bark	26.6	29.5	25.2	1.6	1.7	1.5	0.3	0.3	0.2

Cp= component of above-ground biomass; * significant values at 0.05 level

Phosphorus accumulation observed in this study was similar to the results obtained by Hunter (2001). The concentration of P in branches was somewhat higher than the results showed by Hunter (2001). By other hand, Harrison et al. (2000) showed higher levels of P for this species, which varied as foliage > branches, bole bark, small roots > taproot, coarse roots, bole wood.

Corroborating previous studies (Drechsel and Zech 1991; Harrison et al. 2000), K concentrations in leaves were adequate for satisfactory growth. For all components, *E. camaldulensis* had the highest K concentration (33% higher) (Table 3).

Calcium concentration in *E. grandis* was similar to results showed by Hunter (2001), whereas Ca and Mg contents in *E. camaldulensis* were lower than the data showed by Hunter (2001). Sulfur is an essential element found in plants mostly in its reduced form in amino acids cysteine and methionine. Sulfur contents of the leaves were slightly lower than usual values (1.9 to 3.2 $g \cdot kg^{-1}$) proposed by Dell et al. (1995). Silveira et al. (2003) also found a lower S concentration compared to that proposed in *E. grandis* seedlings leaves. The sulfur content in the total biomass (11 to 12.5 $kg \cdot ha^{-1}$) (Table 3) was higher than that reported by Caldeira *et al*. (2002) for a leguminous tree, *Acacia mearnsii.* Most of the nutrients were concentrated in the leaves and bark. Similar results (leaves) were found by Tandon et al. (1988) in Australian plantations of *E. grandis*, Vezzani (1997) in pure and mixed stands of *Eucalyptus saligna* and *Acacia mearnsii* and in Brazil, by George and Varghese (1990) in *E. globulus.* Nutrient concentration in leaves is influenced by diverse factors such as site conditions, age, position of leaves and season (Van der Driessche 1984). Bellote (1990) observed that nutrient concentration in leaves of *Eucalyptus grandis* in Brazil varies with stand age and with the season. If *E. camaldulensis* canopy concentrates 54.7% of total aboveground biomass nutrients, an exploitation system that preserves these tree components in the site would mean that approx. 403 $kg \cdot ha^{-1}$ of these nutrients could remain in this site.

If we consider plant height alone, there was no significant difference between the two species in the monocultures, whereas, in terms of aboveground dry mass, *E. grandis* performed better than *E. camaldulensis.* The two species thus show a difference in biomass partitioning and accumulation and differ in their concentrations of macronutrients (Table 3). To assess nutrient content

in trees during sampling, an age of three years old must be chosen since at this age *E. grandis* shows larger biomass accumulation per time unit. This is due to three-year-old trees' bigger capacity to absorb soil nutrients and according to Bellote (1990) to the fact that nutrient content in three-year-old *E. grandis* mature leaves shows the highest values.

The inner variability of trees species in longitudinal sense has more drastic effect on the chemical composition of bark than on that of wood. Wood of basal log of the two *Eucalyptus* species presented higher levels of N than the others logs. More apical logs present the highest N and P in the bark, and the highest P in the wood. *E. camaldulensis* showed the highest levels of Ca, Mg and S, at the basal log, and for K, the highest content was in the bark of basal log and wood of apical logs. *E. grandis* showed also more Ca, Mg and S content in basal log wood but, in contrast, bark of apical logs and wood of basal log presents more K (Table 4).

Table 4. Quantification of nutrients of *Eucalyptus camaldulensis* and *E. grandis* inoculated with AMF, 28 months old, at Jaíba, Minas Gerais, Brazil. (Means, N=3)

Species			N (g)	P(g)	K(g)	Ca(g)	Mg(g)	S(g)
E. camaldulensis	Leaves		77.6†	3.3	47.6	95.8	10.1	6.06
	Branches		27.4	2.1	33.1	53.9	3.01	3.3
	Basal logs	Bark	0.14	0.01	0.26	1.62	0.05	0.02
		Wood	11.03	0.46	11.1	10.25	1.55	1.54
	Apical logs	Bark	0.3	0.08	0.13	0.21	0.02	0.009
		Wood	6.3	0.7	13.3	7.76	0.9	0.92
E. grandis	Leaves		138	5.6	45.7	95.3	15.3	7.49
	Branches		57.2	3.7	42.14	79.7	6.6	3.26
	Basal logs	Bark	0.07	0.004	0.06	0.42	0.028	0.005
		Wood	18.5	0.8	13.9	11.39	2.16	1.5
	Apical logs	Bark	0.08	0.07	0.11	0.45	0.03	0.008
		Wood	10.1	0.94	11.6	6.7	1.9	1.17

†= Mean nitrogen content (g) in a plant compartment.

Potassium and Ca are nutrients that could limit productivity in the next cycle, and this limitation can be reduced, if only wood was harvested. To support the optimum soil calcium levels is, therefore, of increasing interest due to the lower levels of this nutrient present in soils cultivated with eucalypt, and to the fact that about 58% of total calcium absorbed is exported by bark removal.

Mycorrhizal colonization varied with *Eucalyptus* species. Assessments of percentage AM and ECM root length for *E. camaldulensis* and *E. grandis* are shown in Table 5. The *E. camaldulensis* AM root colonization (hyphae) was 15%, and vesicles were found in the same percentage. Structures observed suggest a Glomeraceae AM colonization (Sieverding 1991), *Glomus* sp. being relevant for this species at this site (Pagano 2007, Pagano et al. 2008). These results are in accordance with those obtained by Santos et al. (2001) where *E. camaldulensis* presented the highest values of percent AM mycorrhizal colonization among several *Eucalyptus* species and with Adjoud-Sadadu and Halli-Hargas (2000) who reported a <50% AM colonization by this same species. By other hand, levels of AM colonization were lower to those found by Malajczuk et al. (1982) for *E. marginata*. *Eucalyptus* presented a Hartig net (ECM) confined to epidermal cells (Brundrett 2004).

Eucalyptus grandis did not show AM root colonization (Table 5). This may depend on the time of sampling, but ECM was preferentially related with this species. Chen *et al*. (2006) showed that rooting media greatly affected *Scleroderma* colonization of *Eucalyptus urophylla* roots from spore inoculum in nursery experiments. Our results of the dual colonization by ECM and AM fungi in *E. camaldulensis* support the predominance of ECMs (Lapyeyrie and Chilvers 1985, Gardner and Malajczuk 1988, Brundrett *et al*. 1996, Chen *et al*. 2000). ECM colonization of *E. grandis* was similarly to the results presented by Chen *et al*. (2006) for *E. urophylla* (aprox. 50%), whereas AM colonization (10%) was similar to *E. camaldulensis* AM colonization shown in this work. Sustained levels of root colonization above 50% have been mentioned as necessary to ensure high survival and productivity of plantation (Marx *et al*. 1989) accessing sufficient N and P. Ectomycorrhizal fungi are common in eucalypt plantations, being ecologically important in nutrient cycling (Högberg and Högberg 2002, Read and Perez-Moreno 2003). Our observations of abundant basidiocarps (probably *Pisolithus*), especially in *E. grandis* plots, suggest that ECM may enable uptake of immobile phosphorus and other nutrients as has been reported by other references (Smith and Read 1997) reflecting this in plant nutrient content. Thus, the higher nutrient content (especially N and P) in *E. grandis* biomass in this study may be explained by the presence of ECM. On the other hand, AMF have an ecological and agronomic importance in the tropics and their presence can be influenced by environmental factors such as: climate conditions, physical proprieties, soil chemical and physical proprieties, host vegetal species and their age and variety (Cardoso and Kuyper 2006).

Table 5. Mycorrhizal colonization in the homogeneous plantations of 24-month-old *Eucalyptus camaldulensis* and *Eucalyptus grandis* inoculated with AMF at Jaíba, Minas Gerais, Brazil, in the dry period

Colonization	Host plant species	
	Eucalyptus camaldulensis	*Eucalyptus grandis*
AM hyphae	15† a	0 b
AM vesicles	15 a	0 b
ECM	26.66 a b	50 ba

†% colonization; values followed by the same lowercase letter (row) do not differ at P<0.05 as determined by Tukey 5%; AM= arbuscular mycorrhiza; ECM= ectomycorrhiza.

Conclusion

According to the previously described results on *Eucalyptus* spp., it can be concluded that total productivity was of the order *E. grandis* > *E. camaldulensis* and that these species did not reduce growth and aboveground biomass production when cultivated at this site, showing nutrient concentrations similar to that informed in the literature. The highest nutrient concentrations were found in the leaves and the lowest concentrations of N, P, K, Ca and Mg were found in the stem wood, those of S being in the stem wood and bark; wood localized in superior parts of trunk presented

higher concentration of P and bark contained significant amounts of nutrients, especially in *E. grandis*. This points the importance of leaving vegetal slash (mostly crown) on the site in order to decrease the loss of tree productivity in this semiarid region. This work is an approach towards studding *Eucalyptus* in the Southern Brazilian region; further research is necessary, especially regarding litter accumulation, below-ground biomass, and nutrient dynamics.

Acknowledgements

The authors are grateful to CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) for scholarships granted to Marcela C. Pagano. We would also like to thank EMBRAPA – Maize and Sorghum - and EPAMIG – Mocambinho for technical support; and Dr Adriana S. Pagano (Federal University of Minas Gerais) for proofreading of the manuscript.

References

Adjoud-Sadadou D, Halli-Hargas R. 2000. Occurrence arbuscular mycorrhiza on aged *Eucalyptus*. *Mycorrhiza*, **9**: 287-290.

Almeida AC, Soares JV, Landsberg JJ, Rezende GD. 2007. Growth and water balance of *Eucalyptus grandis* hybrid plantations in Brazil during a rotation for pulp production. *For Ecol Manage*, **251**: 10–21.

Arriagada CA, Herrera MA, Ocampo JA. 2007. Beneficial effect of saprobe and arbuscular mycorrhizal fungi on growth of *Eucalyptus globulus* co-cultured with *Glycine max* in soil contaminated with heavy metals. *Journal of Environmental Management*, **84:** 93–99.

Bellote AFJ. 1990. Suprimento de nutrientes minerais e crescimento de plantações adubadas de *Eucalyptus grandis* nos cerrados do Estado de São Paulo. Doctoral Thesis, University de Fraiburg, Fraiburg, Germany.

Bernardo AL, Reis MGF, Reis GG, Harrison RB, Firme DJ. 1998. Effect of spacing on growth and biomass distribution in *Eucalyptus camaldulensis*, *E. pellita* and *E. urophylla* plantations in southeastern Brazil. *For Ecol Manage*, **104**: 1–13.

Boerner REJ. 1984. Foliar nutrient dynamics and nutrient use efficiency of four deciduous tree species in relation to site fertility. *Journal of Applied Ecology*, **21**: 1029–1040.

Brundrett M. 2004. Diversity and classification of mycorrhizal associations. *Biological Reviews*, **79**: 473–495.

Brundrett M, Bougher N, Dell B, Grove G, Malajczuk N. 1996. *Working with Mycorrhizas in Forestry and Agriculture*. ACIAR Monograph 32, ACIAR, Canberra.

Caldeira MVW, Schumacher MV, Spathelf P. 2002. Quantification of nutrient content in above-ground biomass of young *Acacia mearnsii* De Wild., provenance Bodalla. *Annals of Forest Science*, **59**: 833–838.

Campinhos Jr. E. 1999. Sustainable plantations of high-yield *Eucalyptus* trees for production of fiber: the Aracruz case. *New Forests*, **17**: 129–143.

Cardoso IM, Kuyper TW. 2006. Mycorrhizas and tropical soil fertility. *Agriculture Ecosystems & Environment*, **116**: 72–84.

Carvalho PER. 2003. *Espécies arbóreas brasileiras*. Embrapa Informação Tecnológica, Brasília, DF, p. 1039.

Chen YL, Kang LH, Dell B. 2006. Inoculation of *Eucalyptus urophylla* with spores of *Scleroderma* in a nursery in south China: Comparison of field soil and potting mix. *For Ecol Manage*, **222**: 439–449.

Corbeels M, McMurtrie RE., Pepper DA, Mendham DS, Grove TS, O'Connell AM. 2005. Long-term changes in productivity of eucalypt plantations under different harvest residue and nitrogen management practices: A modelling analysis. *For Ecol Manage*, **217**(1): 1–18.

Córdoba AS, Mendonça MMde, Stürmer SL, Rygiewicz PT. 2001. Diversity of arbuscular mycorrhizal fungi along a sand dune stabilization gradient: A case study at Praia da Joaquina, Ilha de Santa Catarina, South Brazil. *Mycoscience*, **42**: 379–387.

Coelho FB, Borges AC, Neves JCL, Barros NF, Muchovej RM. 1997. Caracterização e incidência de fungos micorrízicos em povoamentos de *Eucalyptus grandis* e *Eucalyptus saligna*, nos municípios de Botucatu, São José dos Campos e São Miguel Arcanjo, São Paulo. *R. Árvore*, **21**: 563–573.

Dell B, Malajaczuk N, Grove TS. 1995. *Nutrient disorders in plantation eucalypts*. Canberra: Australian Centre for International Agricultural Research. p. 104.

Drechsel P, Zech W. 1991. Foliar nutrient levels of broad-leaved tropical trees: a tabular review. *Plant Soil*, **131**: 29–46.

Duarte NF, Bucek EU, Karam D, Sa´ N, Scotti MRM. 2006. 551 Mixed field plantation of native and exotic species in 552 semi-arid Brazil. *Aust J Bot*, **54**: 755–764.

EMBRAPA. Empresa brasileira de Pesquisa Agropecuária. 1979. Manual de Análises Químicas de solos, plantas, e fertilizantes. Brasília, DF, Brazil.

Faria GE, Barros NF, Novais RF, Lima JC, Teixeira JL. 2002. Produção e estado nutricional de povoamentos de *Eucalyptus grandis*, em segunda rotação, em resposta à adubação potássica. *R. Árvore*, **26**: 577–584.

Fisher RF, Binkley D (eds). 2000. *Ecology and management of forest soils*. New York: Wiley,

Gardner H., Malajczuk N. 1988. Recolonisation of rehabilitated bauxite mine sites in Western Australia by mycorrhizal fungi, *For Ecol Manage,* **24**: 27–42.

George M, Varghese G. 1990. Nutrient cycling in *Eucalyptus globulus* plantation. I Organic matter production, nutrients accumulation in standing crop and nutrients removal through harvest. *Indian Forestry*, **116**: 42–48.

Gomes SP, Trufem SFB. 1998. Fungos micorrízicos arbusculares (Glomales, Zygomycota) na Ilha dos Eucaliptos, Represa do Guarapiranga, São Paulo, SP. *Acta Bot. Brasilica*, **12**: 393–401.

Gonçalves JLM, Stape JL, Laclau J-P, Smethurst P, Gava JL. 2004. Silvicultural effects on the productivity and wood quality of eucalypt plantations. *For. Ecol. Manage*., **193**, 45–61.

Gonçalves JLM. 1995. Root system adsorption of *Eucalyptus grandis* under different edaphic conditions. *Silvicultura*, **61**: 8–10.

Grazziotti PH, Barros NF, Borges AC, Neves JC, Fonseca S. 1998. Variação sazonal da colonização de raízes de clones de híbridos de eucalipto por fungos micorrízicos no estado do Espírito Santo. *Rev Bras Ciênc Solo,* **22**: 613–619.

Harrison RB, Reis GG, Reis MDGF, Bernardo AL, Firme DJ. 2000. Effect of spacing and age on nitrogen and phosphorus distribution in biomass of *Eucalyptus camaldulensis*, *Eucalyptus pellita* and *Eucalyptus urophylla* plantations in southeastern Brazil. *For Ecol Manage*, **133**: 167–177.

Hopmans P, Stewart HTL, Flinn, DW. 1993. Impacts of harvesting on nutrients in a eucalypt ecosystem in southeastern Australia. *For Ecol Manage*, **59**: 29–51.

Högberg MN, Högberg P. 2002. Extramatrical ectomycorrhizal mycelium contributes one-third of microbial biomass and produces together with associated roots, half the dissolved organic carbon in a forest soil. *New Phytol.*, **154**: 791–795.

Hunter I. 2001. Above ground biomass and nutrient uptake of three tree species (*Eucalyptus camaldulensis*, *Eucalyptus grandis* and *Dalbergia sissoo*) as affected by irrigation and fertiliser, at 3 years of age, in southern India. *For Ecol Manage*, **144**: 189–199.

Jeffries P, Gianinazzi S, Perotto S, Turnau K, Barea JM. 2003. The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. *Biology and Fertility of Soils*, **37**: 1–16.

Kramer PJ, Koslowski TT. 1979. Physiology of woody plants. Academic Press, New York.

Laclau JP, Ranger J, Deleporte P, Nouvellon Y, Saint-André L, Marlet S, Bouillet J. 2005. Nutrient cycling in a clonal stand of *Eucalyptus* and an

adjacent savanna ecosystem in Congo: 3. Input–output budgets and consequences for the sustainability of the plantations. *For Ecol Manage*, **210** (1-3): 375–391.

Lapyeyrie FF, Chilvers GA. 1985. An endomycorrhiza–ectomycorrhiza succession associated with enhanced growth of *Eucalyptus dumosa* seedlings planted in a calcareous soil. New Phytol*.,* **100**: 93–104.

Lemma B, Kleja DB, Nilsson I, Olsson M. 2006. Soil carbon sequestration under different exotic tree species in the southwestern highlands of Ethiopia. *Geoderma*, **136**: 886–898.

Malajczuk N, Linderman, RG, Kough J, Trappe JM. 1981. Presence of vesicular-arbuscular mycorrhizae in *Eucalyptus* spp. and *Acacia* sp. and their absence in *Banksia* sp. after inoculation with *Glomus fasciculatus*. *New Phytologist*, **87**: 567–572.

Malajczuk N, Molina R, Trappe JM. 1982. Ectomycorrhiza formation in Eucalyptus. I. Pure culture synthesis, host specificity and mycorrhizal compatibility with *Pinus radiata*. *New Phytologist*, **91**: 467–482.

Marcar NE, Crawford DF, Leppert PM, Jovanovic T, Floyd R, Farrow R. 1995. *Trees for Saltland: A Guide to Selecting Native Species for Australia*. CSIRO Publications, Melbourne.

Marques Júnior OG, Andrade HB, Ramalho MAP. 1996. Avaliação de procedências de *Eucalyptus cloeziana* F. Muell e estimação de parâmetros genéticos e fenótipos na região noroeste do estado de Minas Gerais. *Cerne*, **2**: 12–19.

Marx DH, Cordell CE, Maul SB, Ruehle JL. 1989. Ectomycorrhizal development on pine by *Pisolithus tinctorius* in bare-root and container seedling nurseries. *New Forests*, **3**: 57–66.

Mason PA, Ingleby K, Munro RC, Wilson J, Ibrahim K. 2000 The effect of reduced phosphorus concentration on mycorrhizal development and growth of *Eucalyptus globulus* Labill. seedlings inoculated with 10 different fungi, *For. Ecol. Manage.,* **128**: 249–258.

Midgley SJ, Eldridge KG, Doran JC. 1989. Genetic resources of *Eucalyptus camaldulensis*. *Common For Rev,* **68**: 295–308.

McGonigle TP, Miller MH, Evans DG., Fairchild GL., Swan JA. 1990. A new method which gives an objective measure of colonization of roots by vesicular-arbuscular mycorhizal fungi. *New Phyto,* **115**: 495–501.

Molina R, Massicote H, Trappe JM. 1992. Specificity phenomena in mycorrhizal symbioses: community–ecological consequences and practical implications. In: Allen, M.J. (ed), *Mycorrhizal Functioning and Integrative Plant-Fungal Process*. London: Chapman & Hall, pp. 357–423.

Nelson DW, Sommer LE. 1982. Total carbon, organic carbon, and organic matter. In: By Page, A. L. (ed), *Methods of soil analysis. Part 2, Chemical and microbiological properties*, Wisconsin: Amer. Soc. Agron., Inc., Soil Sci. Soc., Inc. Madison, pp. 539–579.

Pagano MC. 2007. *Characterization of Glomalean mycorrhizal fungi and its benefits on plant growth in a semi-arid region of Minas Gerais (Jaíba Project), Brazil*. PhD thesis, Federal University of Minas Gerais, Belo Horizonte, Brazil. p. 163.

Pagano MC, Cabello MN, Bellote AF, Sa NM, Scotti MR. Intercropping system of tropical leguminous species and *Eucalyptus camaldulensis*, inoculated with rhizobia and/or mycorrhizal fungi in semiarid Brazil. *Agroforest Syst*. **74**: 231–242. 2008.

Pampolina NM, Dell B, Malalczuk N. 2002. Dynamics of ectomycorrhizal fungi in a *Eucalyptus globulus* plantation: effect of phosphorus fertilization. *For Ecol Manage*, **158**: 291–304.

Phillips JM, Hayman DS. 1970. Improved procedures for clearing roots and staining parasitic and vesicular mycorrhizal fungi for rapid assessment of infection. *Trans Brit Mycol Soc*, **55**: 158–161.

Pereira AR, Andrade DC, Barros NF, Fonseca AG, Leal PGL, Lucia MAD, Gomes JM. 1984. *Produção de biomassa e acumulação de nutrientes em florestas de ciclos curtos*. Publication of Sociedade de Investigações Florestais. Federal University of Viçosa, Minas Gerais, Brazil.

Poggiani F, Couto HTZ, Suiter RW. 1983. Biomass and nutrient estimates in short rotation intensively cultured plantations of *Eucalyptus grandis*. *J. IPEF*, **23**: 37–42.

Prado DE. 2003. As Caatingas de América do Sul. Seção I. Padrões de diversidade e distribuição das espécies em escala regional. In: I.R. Leal, M. Tabarelli and J. M. C. da Silva (eds), *Ecologia e Conservação da Caatinga*, Recife: Edit. Universitária, pp 1–74.

Read DJ, Perez-Moreno J. 2003. Mycorrhizas and nutrient cycling in ecosystems – a journey towards relevance? *New Phytol*, **157**: 475–492.

Rillig, MC. 2004. Arbuscular mycorrhizae and terrestrial ecosystem processes. *Ecol. Letters*, **7**: 740–754.

Santos VL, Muchovej RM, Borges AC, Neves JCL, Kasuya MCM. 2001. Vesicular-arbuscular-ectomycorrhiza succession in seedlings of *Eucalyptus* spp. *Braz. J. Microbiol.*, **32**: 81–86.

Sarruge JR, Haag HP. 1974. Análises químicas em plantas. Ed. Escola Superior de Agricultura "Luiz de Queiroz", Piracicaba, São Paulo, Brazil.

Schumacher MV, Poggiani F. 1993. Produção de biomassa e remoção de nutrientes em povoamentos de *Eucalyptus camaldulensis* Dehnh, *Eucalyptus grandis* Hill ex Maiden E *Eucalyptus torelliana* F.Muell, plantados em Anhembí, SP. *Sci Flor*, **3**: 21–34.

Shimoyama VRS. 1990. Variações da densidade básica e características anatômicas e químicas da madeira de *Eucalyptus* spp.. M. S. Thesis, Escola Superior de Agricultura "Luiz de Queiroz", Piracicaba, Brazil.

Sieverding E. 1991. *Vesicular-arbuscular mycorrhiza management in tropical agrosystems*. Eschborn: Deutsche Gesellschaft für Technische Zusammenarbeit.(GTZ) GmnBH, Esch boran, 371 pp.

Silveira LVA, Luca EF, Silveira LVA, Luz HF. 2003. Dry matter, macronutrients concentration and content in *Eucalyptus* seedlings according to the age. *Scientia Florestalis,* **64**: 136–149.

Smith SE, Read DJ. 1997. *Mycorrhizal Symbiosis*. Academic Press, Inc., London, UK. 489 pp.

Standish RJ, Stokes BA, Tibbett M, Hobbs RJ. 2007. Seedling response to phosphate addition and inoculation with arbuscular mycorrhizas and the implications for old-field restoration in Western Australia. *Env Exp Bot*, **61**: 58–65.

Tandon VN, Pande MC, Singh R. 1988. Biomass estimation and distribution of nutrients in five different aged *Eucalyptus grandis* plantations ecosystems in Kerala state. *The Indian Forester,* **114**: 184–199.

Timmer VR, Morrow LD. 1984. Predicting fertilizer growth response and nutrient status of jack pine by foliar diagnosis. In: E.L. Stone (ed), *Forest Soil and Treatment Impacts*. Knoxville: Univ. of Tennessee.

Thomson BD, Hardy GEStJ., Malajczuk N, Grove TS. 1996. The survival and development of inoculant ectomycorrhizal fungi on roots of outplanted *Eucalyptus globulus* Labill. *Plant Soil*, **178**: 247–253.

Van der Driessche R. 1984. Prediction of mineral status of trees by foliar analysis. *The Botanical Review,* **40**: 347–394.

Vezzani FM. 1997. Aspectos nutricionais de povoamentos puros e mistos de *Eucalyptus saligna* (Smith) e *Acacia mearsnii* (De Wild.). M.S. Thesis, Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil.

Young HE, Carpenter PN. 1976. Sampling variation of nutrient element content within and between on trees of the same species. In: *Oslo Biomass Studies*. Oslo, Proceedings.

Zambolim L, Barros NF. 1982. Constatação de micorriza vesicular-arbuscular em *Eucalyptus* spp. na região de Viçosa, MG. *Rev Árvore*, **6**: 95–97.